Applying PSA for CAP1400 and Additional R&D after the Fukushima Accident

IEM-8

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Shanghai Nuclear Engineering Research and Design Institute

Chinese Spring Festival Gala Evening

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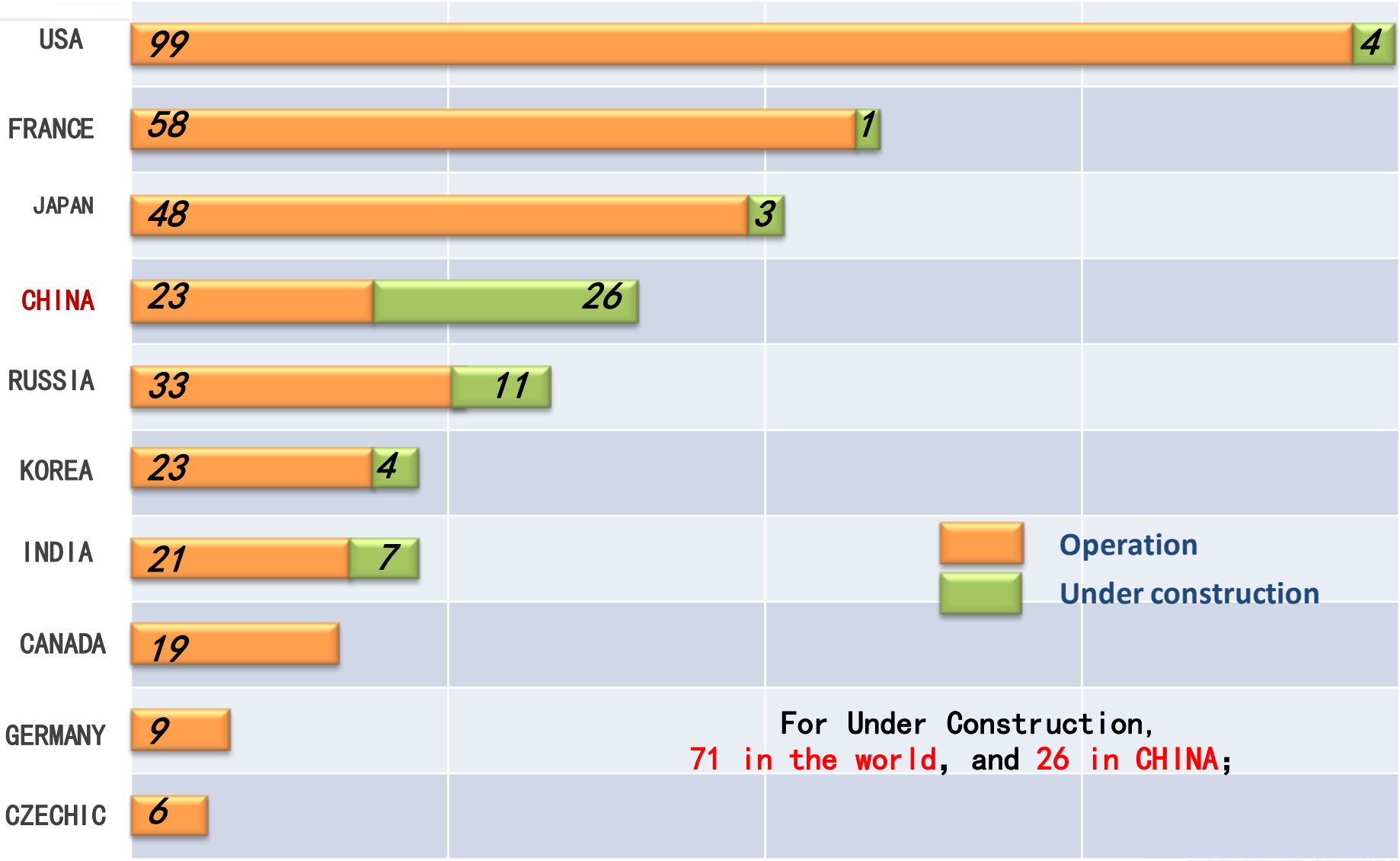
福岛后的中国核电发展

Nuclear Power Development Strategy after Fukushima Accident

Nuclear Power Plant in the World



For Under Construction,
71 in the world, and 26 in CHINA;

NPPs in mainland China

Nuclear Development Plan

2012年，国务院常务会议相继通过国家《核安全规划》和《核电中长期发展规划》等四个文件，明确了国家顶层规划：

On Oct.24,2012, Chinese government issued a "Mid to long term nuclear development plan(2011-2020)", decided national overall planning.

- 坚持"在安全的基础上高效发展核电"；

Safely And Effectively Develop Nuclear Power .

- 采用最严格的安全标准，最先进的技术;

The Most Strictest Safety Standard , The Most Advanced Technology.

- 新建核电项目技术路线以AP1000及其再创新为主；

GIII AP1000 technology and its successive re-innovation technology as future trends of nuclear power.

Nuclear Safety Planning

- In Oct. 2012, the State Council approved Nuclear Safety Planning.

核安全发展规划

Nuclear Safety Planning

NNSA

2012.10

The high level safety goals for the Twelfth Five-Year **(2010-2015)** is described as follows: severe accident prevention and mitigation measures should be considered thoroughly in the design, and core damage frequency and large release frequency should be assessed to be lower than 1E-5/reactor-year, 1E-6/reactor-year respectively.

As for the NPPs which will be built in China's Thirteenth Five-Year **(2016-2020)** and later, the high level safety goal is described as "the possibility of the large radioactive release should be **practically eliminated** by design"

Safety Enhancement after accident

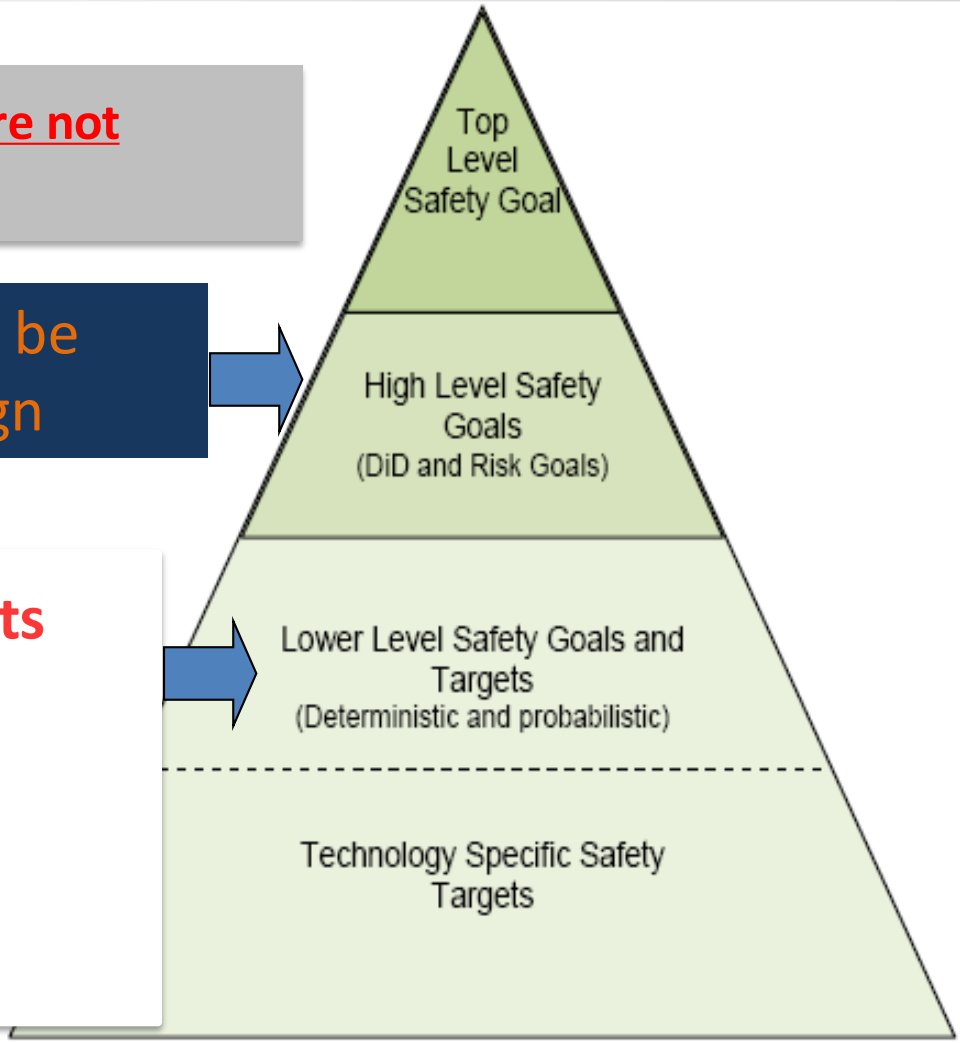
福岛事故后的安全裕度提高措施 Safety Enhancement after Fukushima Accident

- 防水封堵预案 Water proof plugging scheme (backup)
- 72小时后补水保障措施 Water supply after 72 hours
- 72小时后电源保障措施（增设移动式柴油发电机） **Power supply after 72 hours (moveable diesel generator)**
- 增强乏燃料池水位监测仪 Enhance spent fuel pool level monitor instrument
- 环境监测设计改进 Environment monitoring design improvement
- 强化应急指挥中心设计 Improve emergency command center design
- 全范围SAMG **Full scope SAMG**

Technical insight of practical elimination

Warning: the insight discussed below are not formally published in China

large radioactive release should be **practically eliminated** by design



Lower Level safety Goals and Targets

- ❑ **Large radioactive release**
- ❑ **DiD Goals (Deterministic)**
- ❑ **Risk Goals (Probabilistic)**

IAEA-CN-205 G. SHI have gave a detail information

Ongoing R&D Activities

- **From technical point of view, the activities are related to the following areas**
  - ✓Earthquake
  - ✓Flooding
  - ✓Improvement of power and water supply
  - ✓Spent fuel pool
  - ✓Hydrogen control
  - ✓Severe accident management
  - ✓Filtered venting
  - ✓**PSA**
  - ✓others

  - **seismic PSA (2013-2017)**
  - **Risk from spent fuel pool (2013-2015)**
  - **Level 2 PSA for shutdown condition (2013-2015)**

上海核工院简介

Overview of Shanghai Nuclear Engineering Research and Design Institute(SNERDI)

Introduction of SNERDI

国家核电 SNPTC 上海核工程研究设计院 SHANGHAI NUCLEAR ENGINEERING RESEARCH & DESIGN INSTITUTE

– Shanghai Nuclear Engineering Research and Design Institute (SNERDI), located in Xuhui district, Shanghai, east China, was established on Feb. 8th, 1970. ---@728

Introduction of SNERDI

SNERDI has become a subsidiary of the State Nuclear Power Technology Corporation (SNPTC) since June 2007.

Position of SNPTC

1. 代表国家对外签约，受让第三代先进核电技术

On behalf of Chinese government, to introduce advanced 3rd generation nuclear power technology;

2. 是通过消化、吸收、再创新形成中国核电技术品牌的主体；

To develop China’s own brand name nuclear power technology through assimilation, absorption and innovation ;

3. 是实现第三代核电技术引进、工程建设和自主化发展的主要载体和研发平台。

SPNTC is a key entity and platform for 3rd generation nuclear power technology introduction, project construction and self-reliance development.

Introduction of SNERDI

SNERDI是中国3家核电设计院之一，具备完整的核岛设计能力。

SNERDI is **one of the three research and design institutes** on nuclear power plant in China.

1. Class A qualification of **engineering design**
2. Class A qualification of **engineering consulting**
3. Class A qualification of **project supervising**
4. Class A qualification of **radioactive protection evaluation**
5. Class A qualification of **environment impact evaluation**
6. Qualification of **nuclear pressure retaining component design** (issued by NNSA)
7. Class1, Class2, and Class 3 qualification of **pressurized vessel design**
8. Class A qualification of **architectural decoration design**.
9. In total, 16 Class A, 5 Class B **certificates and/or qualifications.**

Introduction of SNERDI

- 中国大陆第一座商用核电厂—秦山核电厂的设计。 **The 1st NPP in mainland of China, Design of Qinshan 300MWe NPP with 2 loops PWR.**
- 中国第一个出口核电站—巴基斯坦恰希玛核电站的设计。 **Design of Pakistan Chashma NPP Unit 1.**
- 中国进口CANDU-6重水反应堆的技术总支持。 **Technical support to Chinese imported CANDU-6 HWR.**

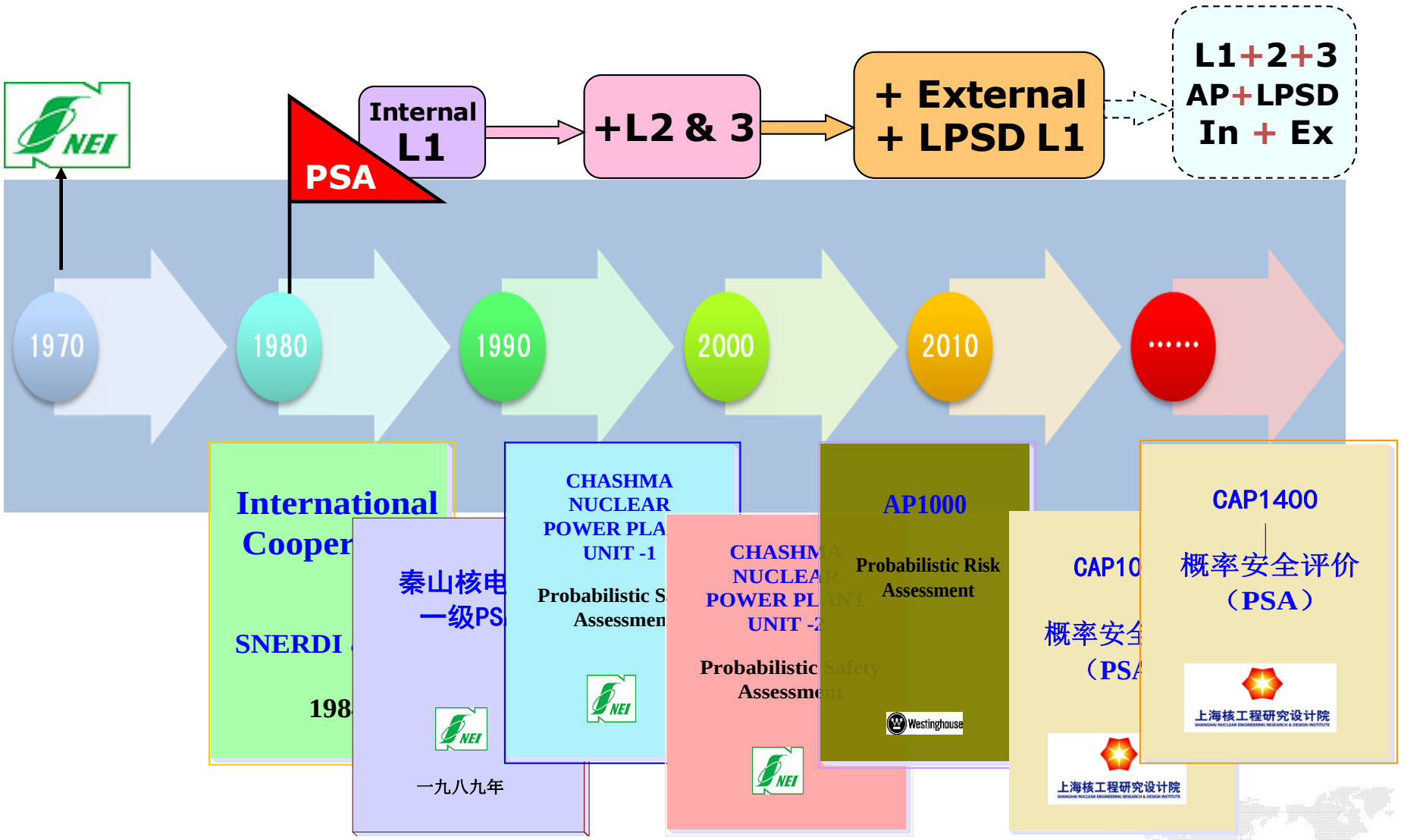
Introduction of SNERDI

国家核电 SNPTC 上海核工程研究设计院 SHANGHAI NUCLEAR ENGINEERING RESEARCH & DESIGN INSTITUTE

Engineering ongoing:

- Overall Design of AP1000 Self-Reliance project for **Sanmen and Haiyang**
- AP1000 technology transferring (TT), Digestion and Absorption
- The Standardization Design of CAP1000
- **The large passive PWR, CAP1400**
- The development of SMR & CAP Series
- Design for Chashma NPP-3/4

Introduction of SNERDI's PSA



CAP1400 PSA 概述

Large Advanced PWR Project PSA

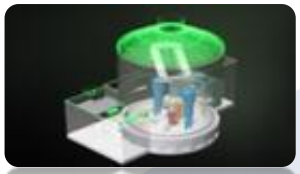
Demonstration Project

国家核电 SNPTC 上海核工程研究设计院 SHANGHAI NUCLEAR ENGINEERING RESEARCH & DESIGN INSTITUTE

Key milestones of CAP1400 demonstration plant:

2010

Conceptual Design Completed



2011

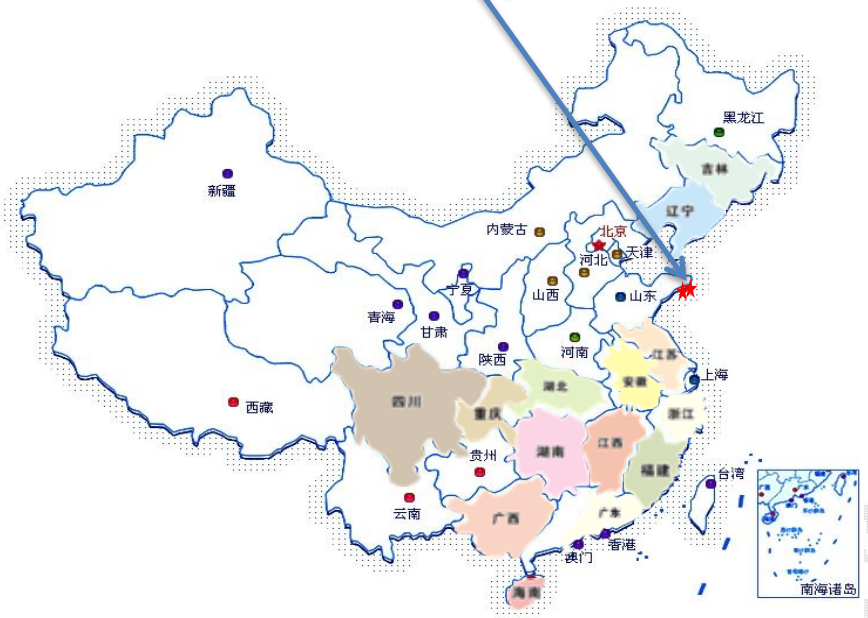
Basic Design Completed

2015

FCD

2018

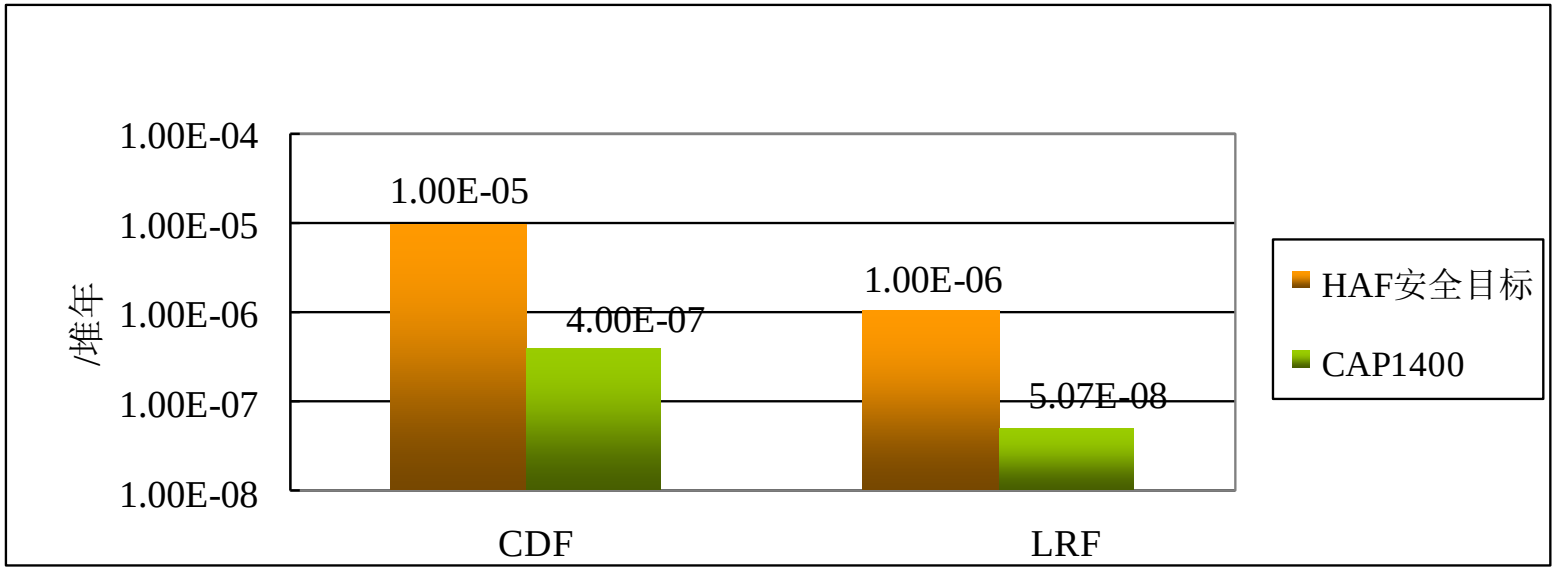
Connected to Grid

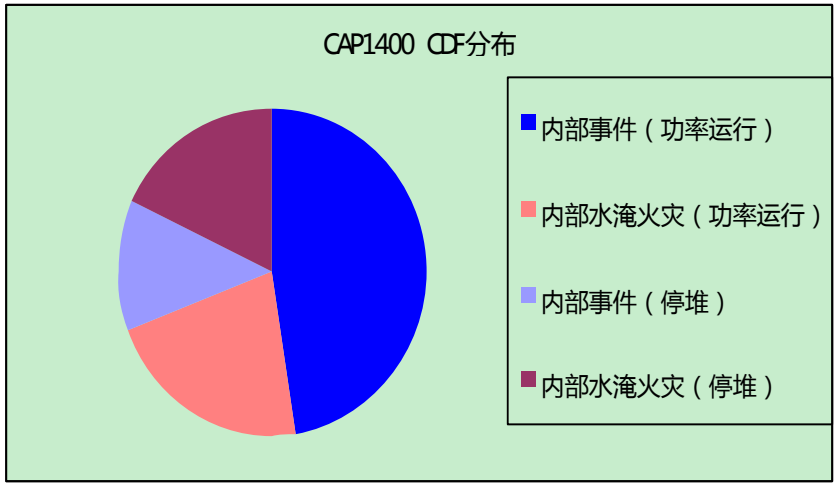


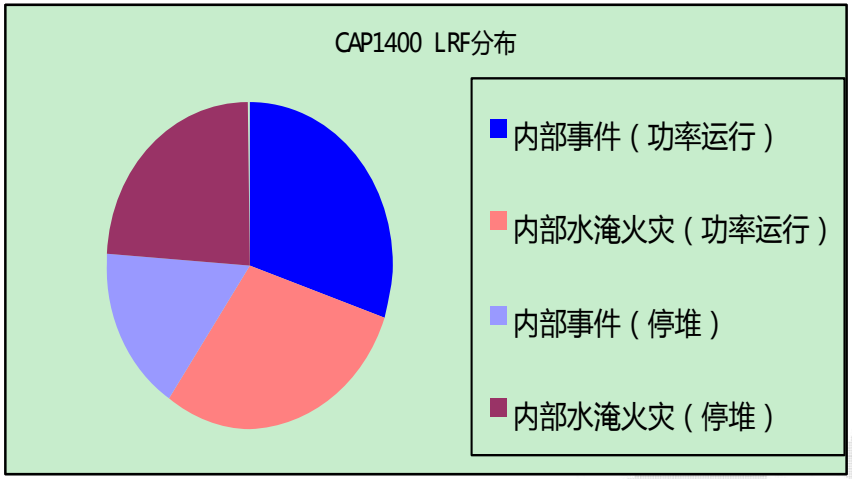
Main Technical Features

Main Technical Indicators	CAP1400	Nuclear Power Unit Compared
Heat (electric) power	4040MWt(1500MWe)	3983MWt(1400MWe)
Power plant availability	＞93%	＞90%
Designed lifetime	60 yrs	60 yrs
Refueling cycle	18~24 months	18 months
Construction period	48 months	52 months
Safety features	passive	active
Thermal margin（DNBR）	＞15%	＞10%
Core damage probability	**＜10^{-6}/year**	**＜10^{-5}/year**
Large-scale radioactive release probability	**＜10^{-7}/year**	**＜10^{-6}/year**
Operator response time	72 hours of non-intervention	＞30 min
Value Ratio Investment	Lower than others	

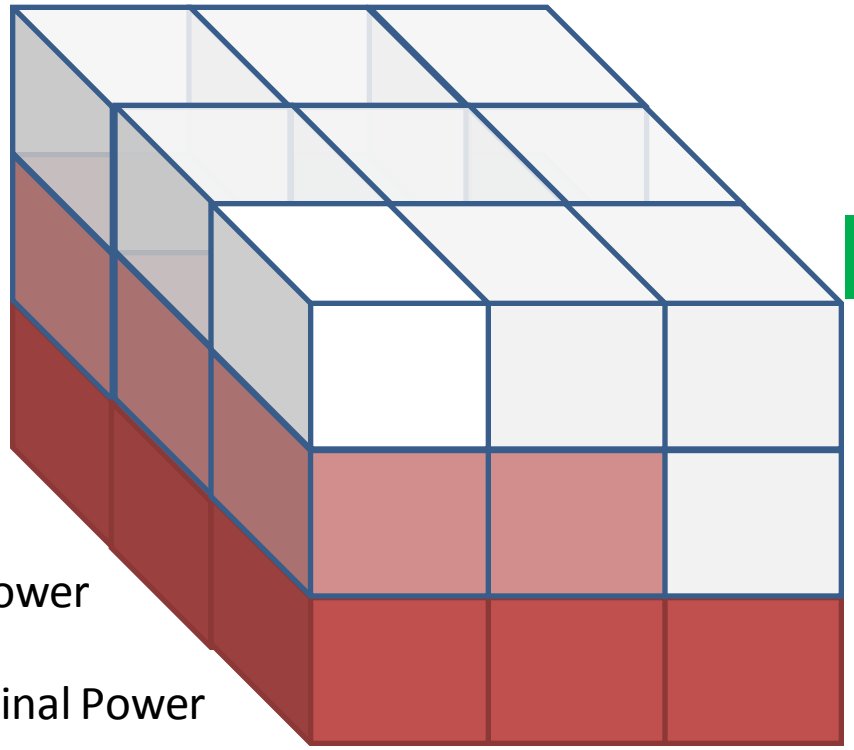
CAP1400 PSA results







CAP1400 PSA Scope



Operating Modes

Shutdown

Low Power

Nominal Power

Initiating Events

External Hazards

Internal Hazards

Internal Events

1 2 3

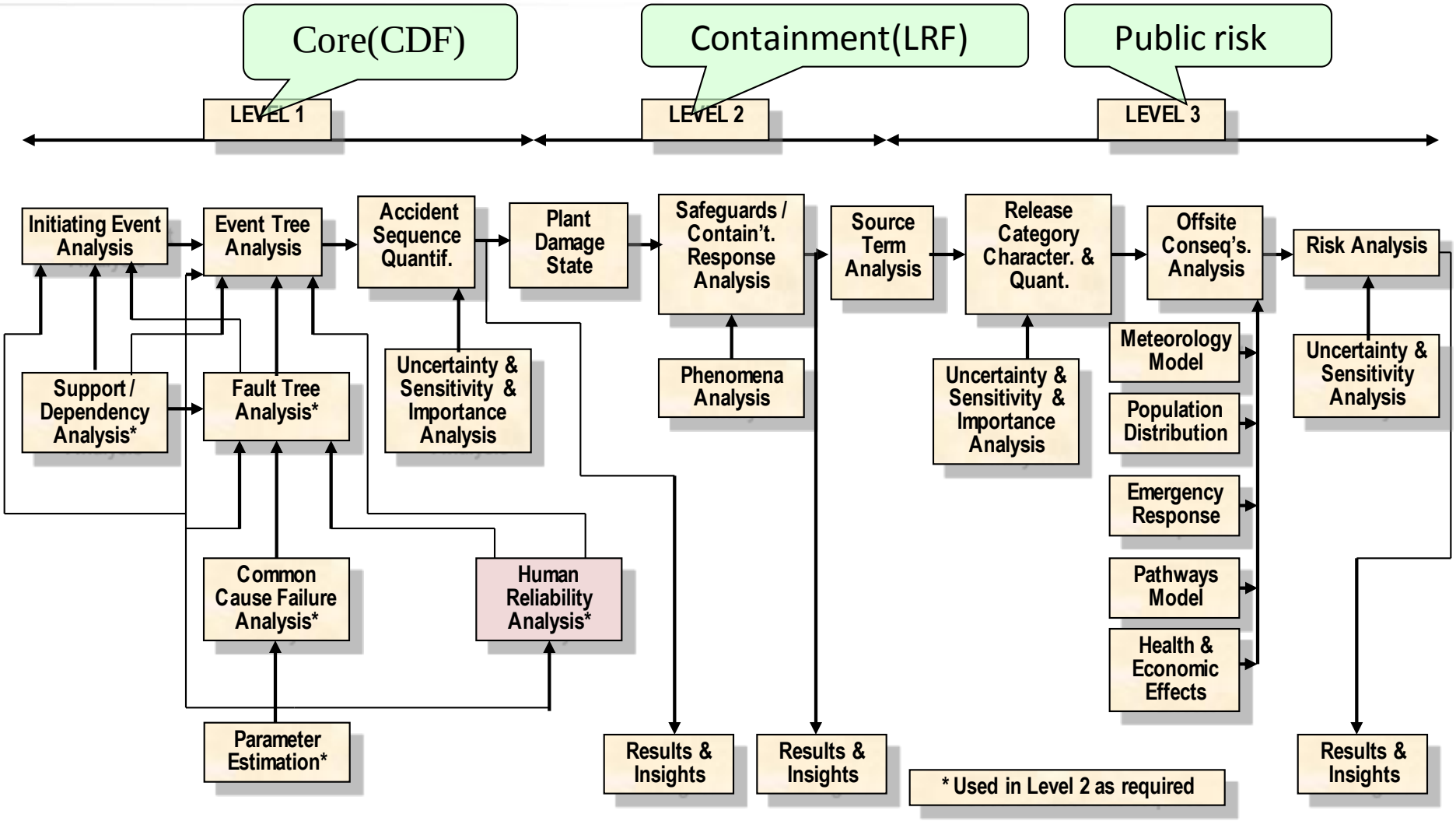
PSA Levels

At power & LPSD Events PSA release from the core exclude the SFP

CAP1400 PSA External events

- **The following external events (groups) are typically further analyzed after screening analysis:**
  - Internal fire
  - Internal flooding
  - Seismic events——SMA
  - High winds
  - External flooding
  - Transportation and nearby facility accidents, etc

CAP1400 PSA -Framework



Framework of analysis process and elements of internal event PSA under at-power condition

Regulations and Standards

- **The Chinese Nuclear Safety Regulations and Standards :**

1) **HAF102**, 核动力厂设计安全规定，2004.4. (Safety of Nuclear Power Plants: Design)

2) **HAD102/01**，核电厂设计总的安全原则，1989.7
(Fundamental Safety Principles in Design of NPP)

3) **HAD102/17**，核动力厂安全评价与验证，2006.6
(Safety Assessment and Verification for Nuclear Power Plants)

4) **NB/T 20037.1-2011** 应用于核电厂的概率安全评价第1部分：功率运行内部事件一级PSA (Probabilistic Safety Assessment with application for NPPs Part 1: Internal events at-power level 1 PSA)

5) **NB/T 20037.2-2012** 应用于核电厂的概率安全评价 第2部分：低功率和停堆工况内部事件一级PSA (Probabilistic Safety Assessment with application for NPPs Part 2: Low power & shutdown level 1 PSA)

6) **NB/T 20037.3-2012** 应用于核电厂的概率安全评价 第3部分：水淹 (Probabilistic Safety Assessment with application for NPPs Part 3: Flooding)

7) **NB/T 20037.4-2013** 应用于核电厂的概率安全评价 第4部分：火灾 (Probabilistic Safety Assessment with application for NPPs Part 4: Fire)

Regulations and Standards

- **IAEA Nuclear Safety Regulations and Standards :**

1) **IAEA SSG-3,** Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants, Specific Safety Guide.

2) **IAEA SSG-4,** Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plants, Specific Safety Guide.

3) **IAEA NS-G-1.5** External events excluding earthquakes in the design of nuclear power plants.

4) **IAEA NS-G-2.15** Severe Accident Management Programmes for Nuclear Power Plants.

Regulations and Standards

- **American Nuclear Safety Regulations and Standards :**

1) Code of Federal Regulations **10 CFR 50**, May 2010.

2) Regulatory Guide **(RG) 1.200** An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities.

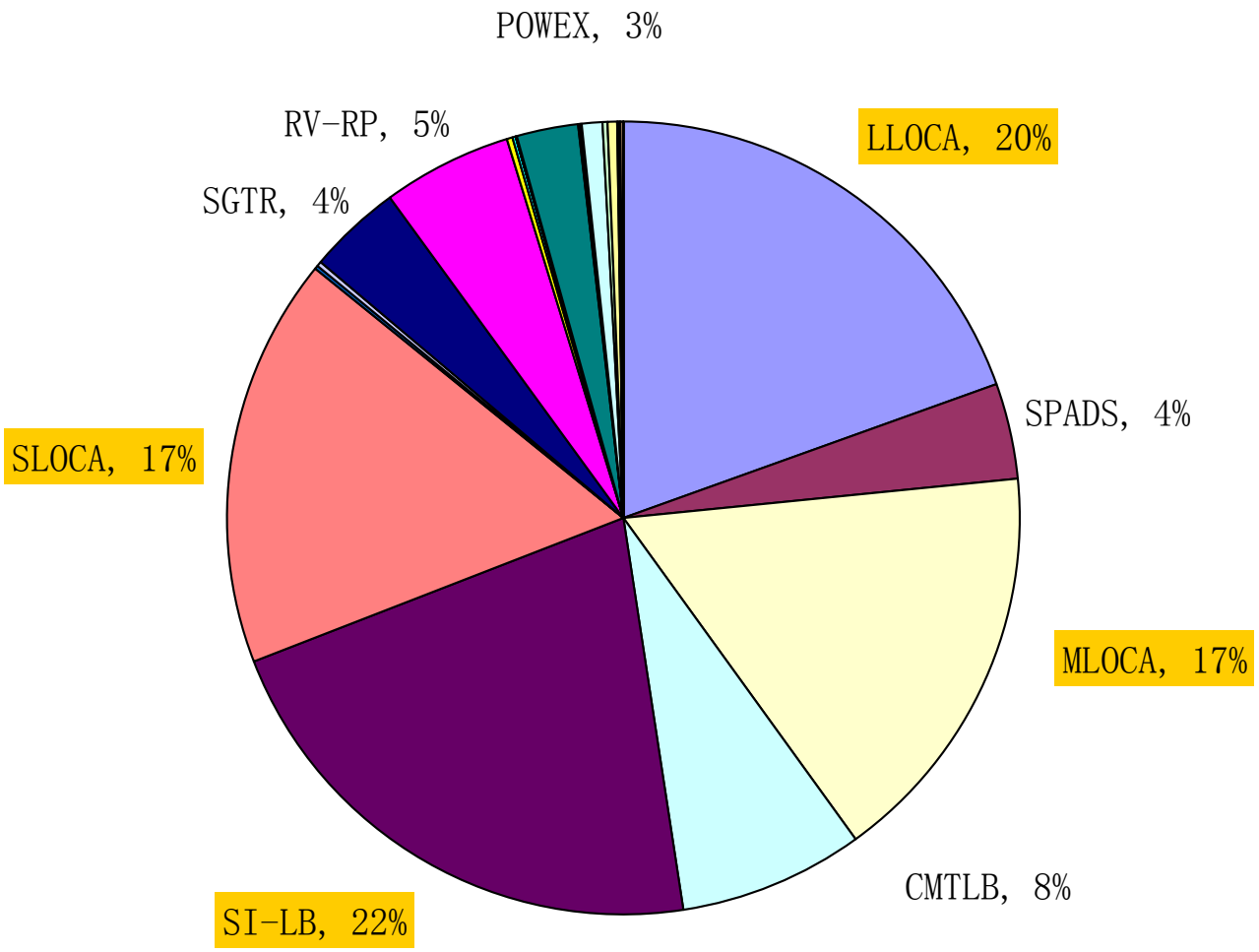
3) **RG 1.206** Combined License Applications for Nuclear Power Plants (LWR)

4) **NUREG-0800**, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants， 2007.

5) American Society of Mechanical Engineers (ASME)/American Nuclear Society (ANS) RA--Sa-2009, Addenda to **ASME/ANS RA-S**–2008, Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications.

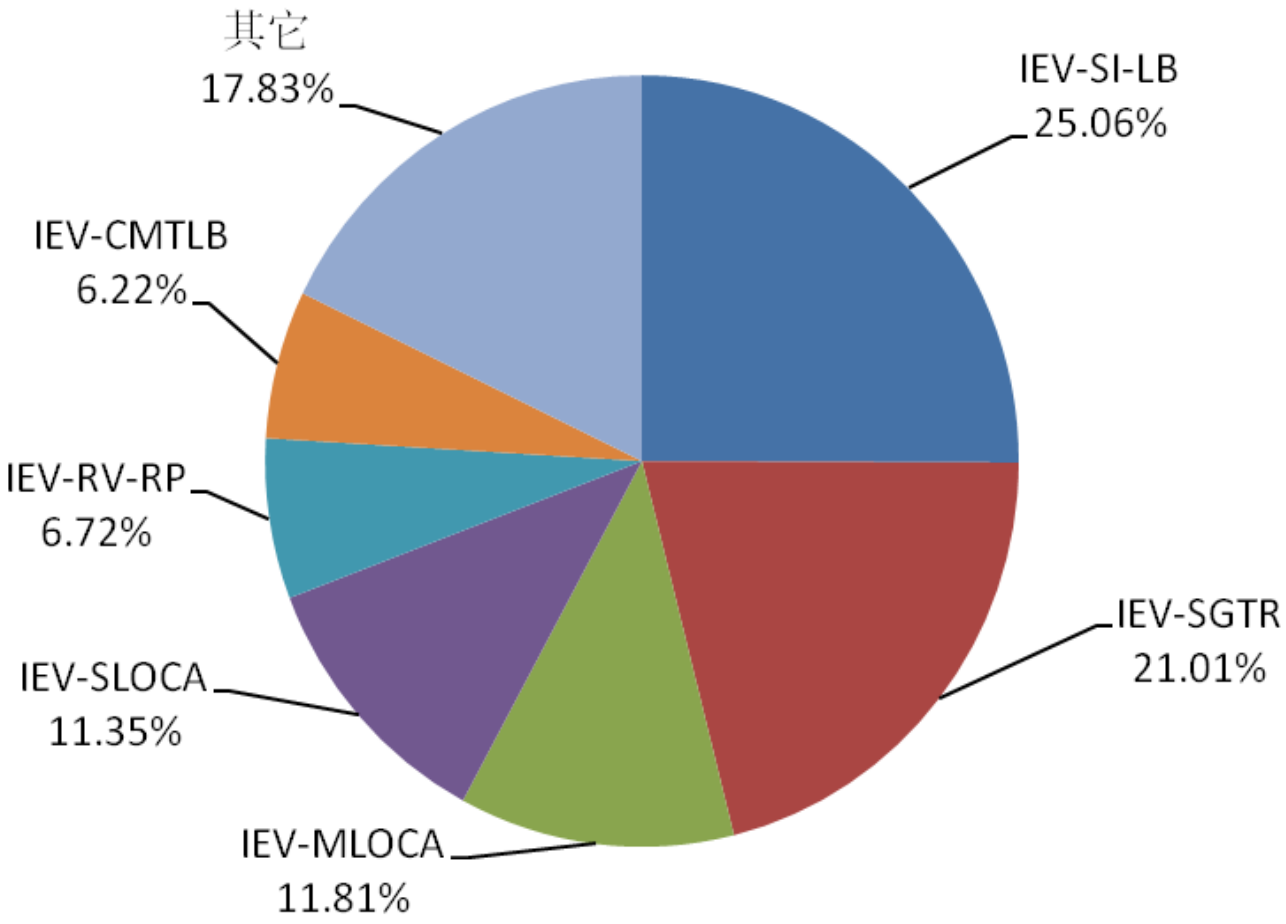
6) **NFPA 804** Standard for Fire Protection for Advanced Light Water Reactor Electric Generating Plants.

CDF for internal events



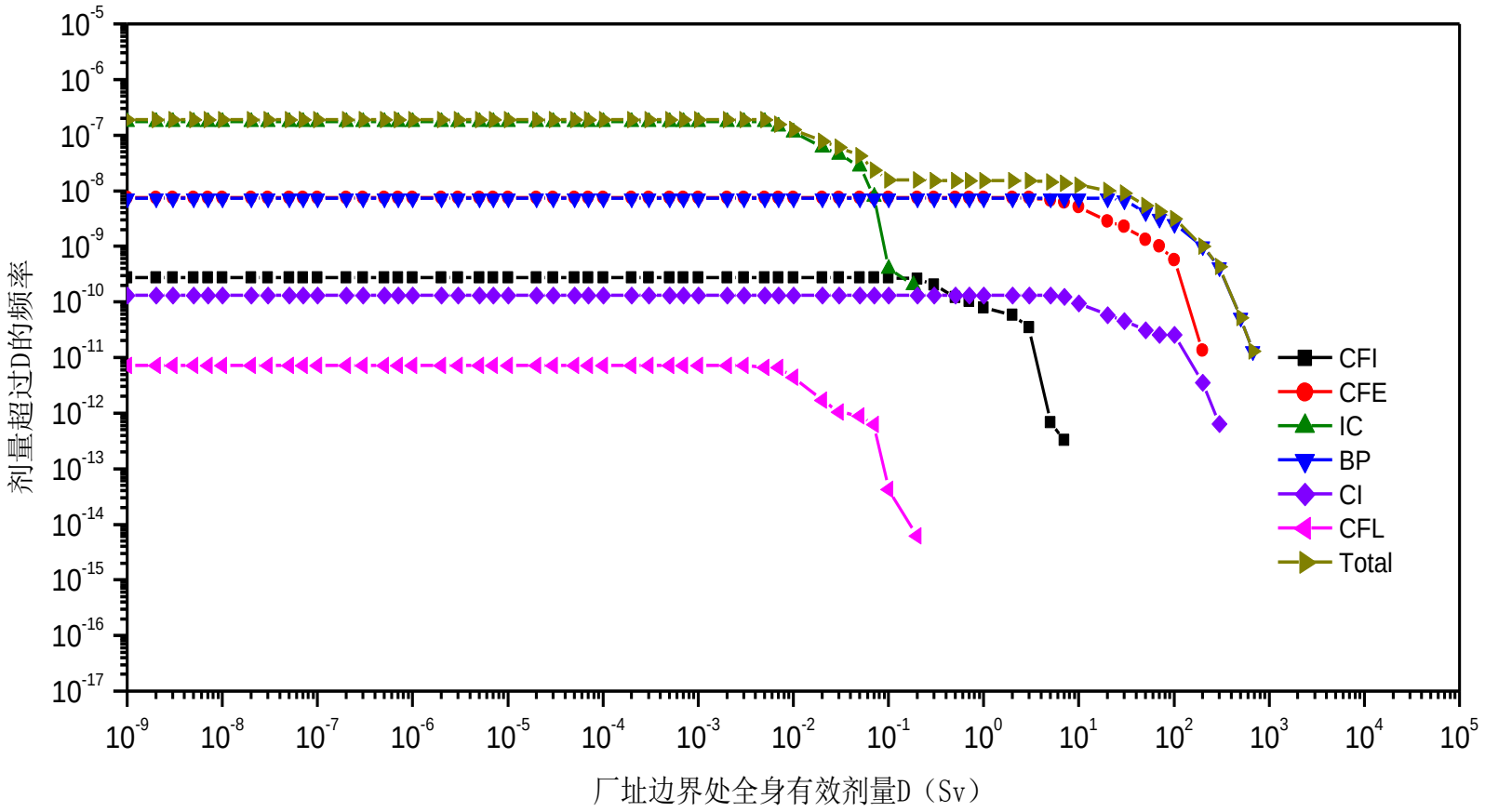
CAP1400 at power internal events- Contribution Of Initiating Events To Core Damage

LRF for internal events



CAP1400 at power internal events- Contribution Of Initiating Events To Large Release

Source Term and Consequence



Site Boundary Whole Body Dose，24h

LPSD PSA results

- LPSD PSA result analysis ：

	CAP1400	AP1000	AP600
• Source：			
• LPSD CDF：	5.12E-08/y	1.23E-7/y	1.0E-7/y

The result indicates：

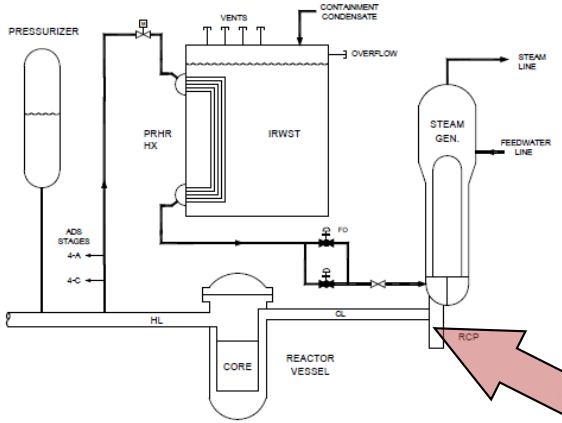
- ◆ The risk of CAP1400 under LPSD condition **is very Low**；
- ◆ The LPSD CDF equals approximately **a quarter** of the at power internal events' CDF, and could not be ignored.

Summary of CAP1400 PSA Results

Events	Core Damage Frequency（CDF）(per year)		Large Release Frequency（LRF）(per year)	
	At-Power	Shutdown	At-Power	Shutdown
Internal Events	**1.90E-07**	5.12E-08	**1.53E-08**	8.54E-09
Internal Flood	4.43E-10	1.35E-09	1.44E-10	2.25E-10
Internal Fire	8.67E-08	7.08E-08	1.47E-08	1.18E-08
High Wind	2.03E-09	--	1.33E-09	--
Sum	2.79E-07	1.23E-07	3.15E-08	2.06E-08
Total	**4.02E-07**		**5.21E-08**	
HAD Safety goal	1E-05		1E-06	
NRC Safety goal	1E-04		1E-06	
URD Safety goal	1E-05		1E-06	

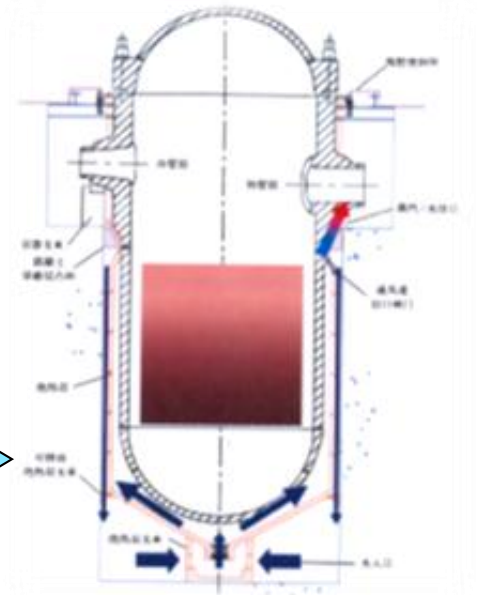
PSA Applying and insights

Dives control system



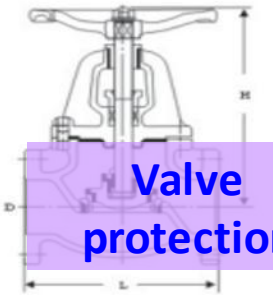
PXS model

PSA improvement



IVR

Add VEWFDS



Valve protection

On-Going R&D Activities

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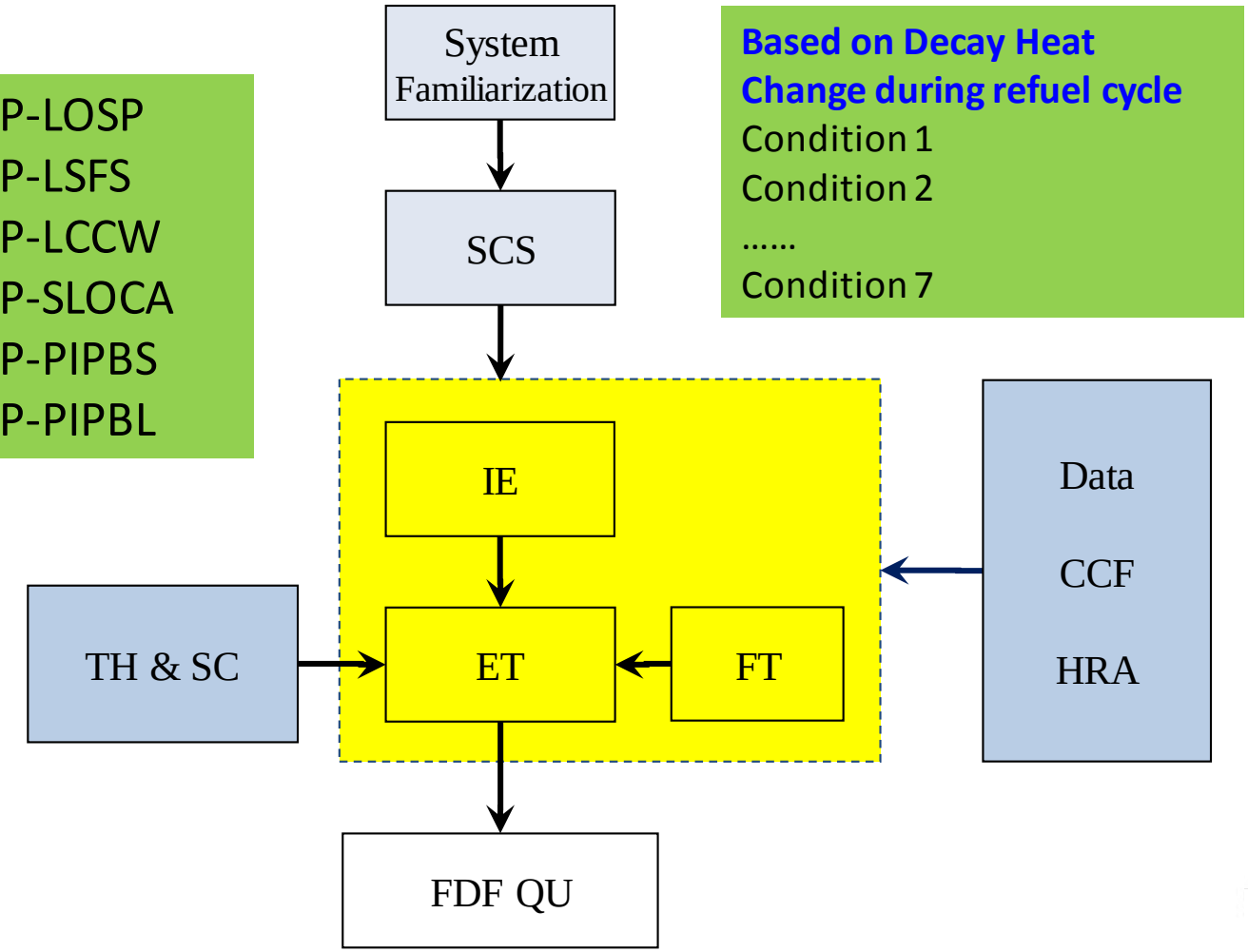
- **Risk from spent fuel pool (2013-2015)**

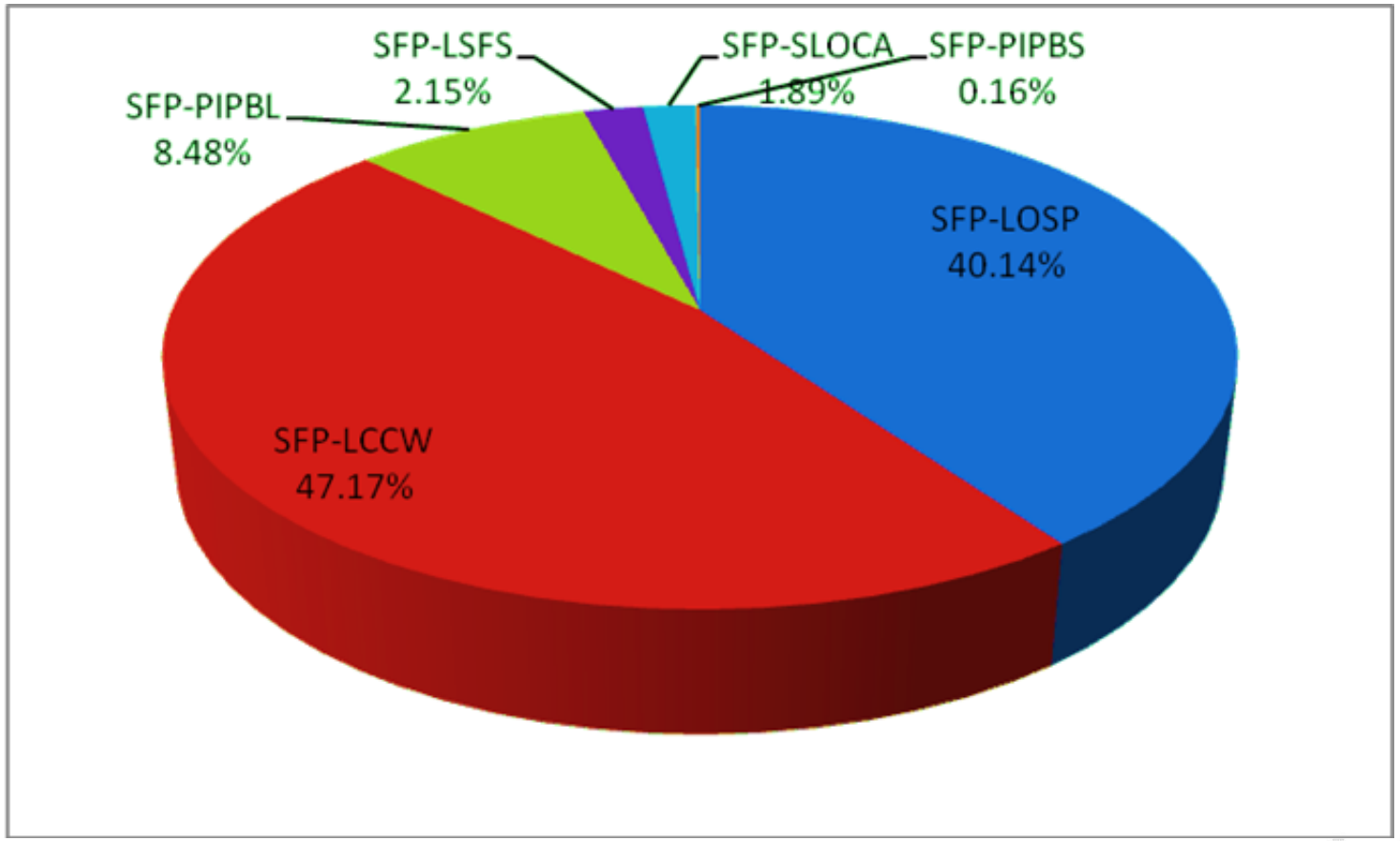
SFP-LOSP
SFP-LSFS
SFP-LCCW
SFP-SLOCA
SFP-PIPBS
SFP-PIPBL



Based on Decay Heat Change during refuel cycle
Condition 1
Condition 2
……
Condition 7

On-Going R&D Activities

- **Risk from spent fuel pool (2013-2015)**



On-Going R&D Activities

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• seismic PSA (2013-2017)

Probabilistic Seismic Hazard Analysis (PSHA)

- SSHAC+CPSHA

Fragility Analysis

- Conservative Deterministic Failure Margin (CDFM)+Hybrid
- Fragility Analysis/Generic data

System Analysis

- SET + internal event PSA model

Quantification

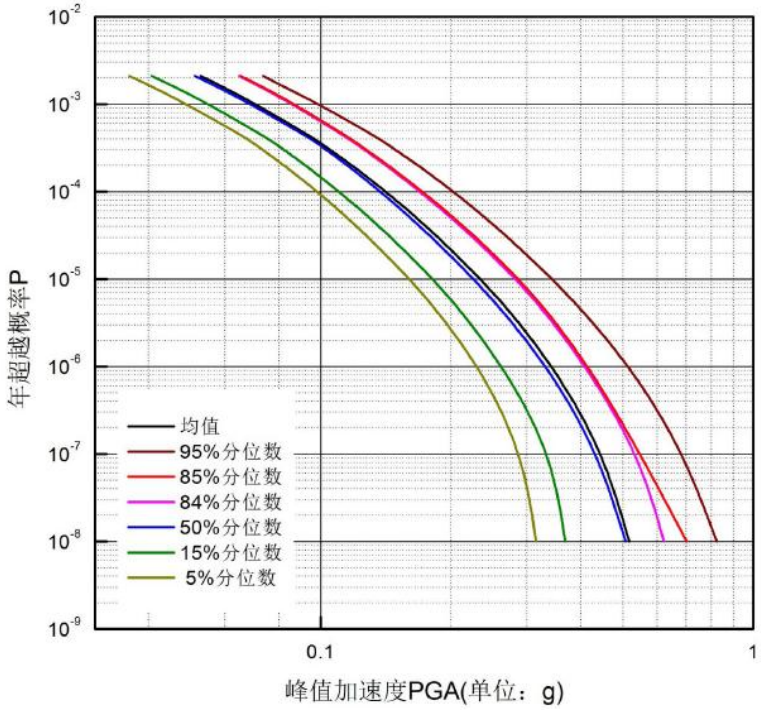
- Monte Carlo
- Binary Decision Diagram

On-Going R&D Activities

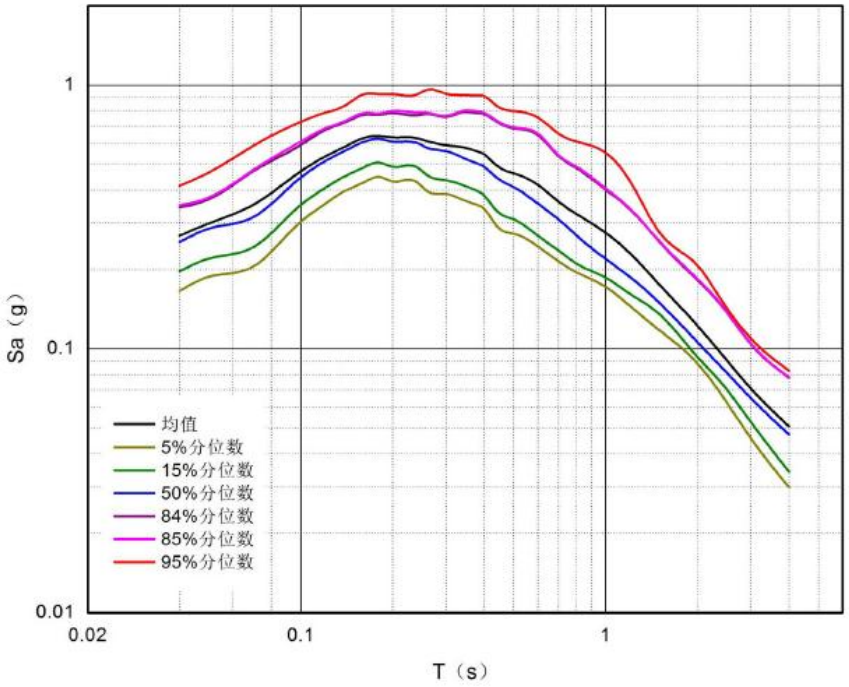
国家核电 SNPTC 上海核工程研究设计院 SHANGHAI NUCLEAR ENGINEERING RESEARCH & DESIGN INSTITUTE

• seismic PSA (2013-2017)

PSHA results of Shidaowan site, China



Hazard Curves



UHRS (1×10^{-5} AFE)

On-Going R&D Activities

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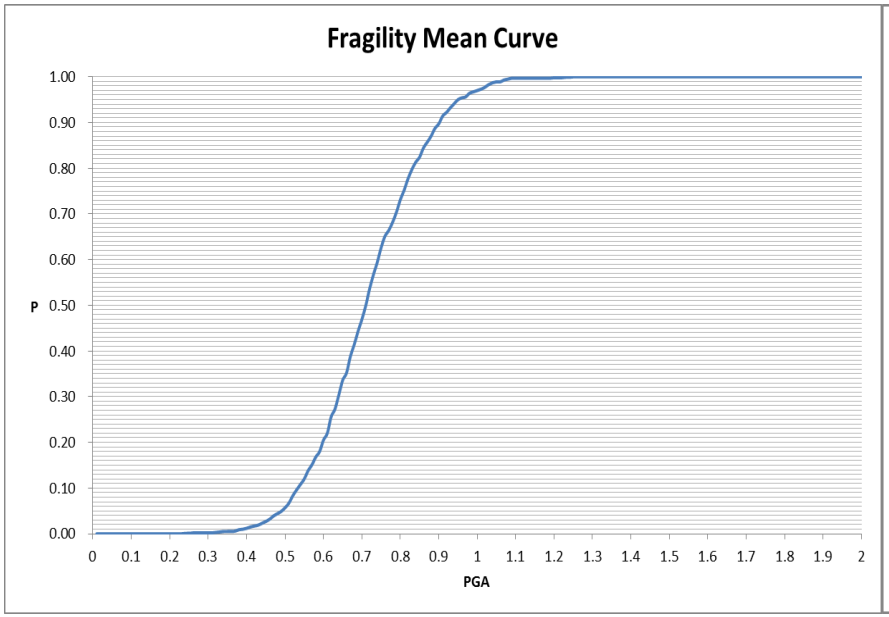
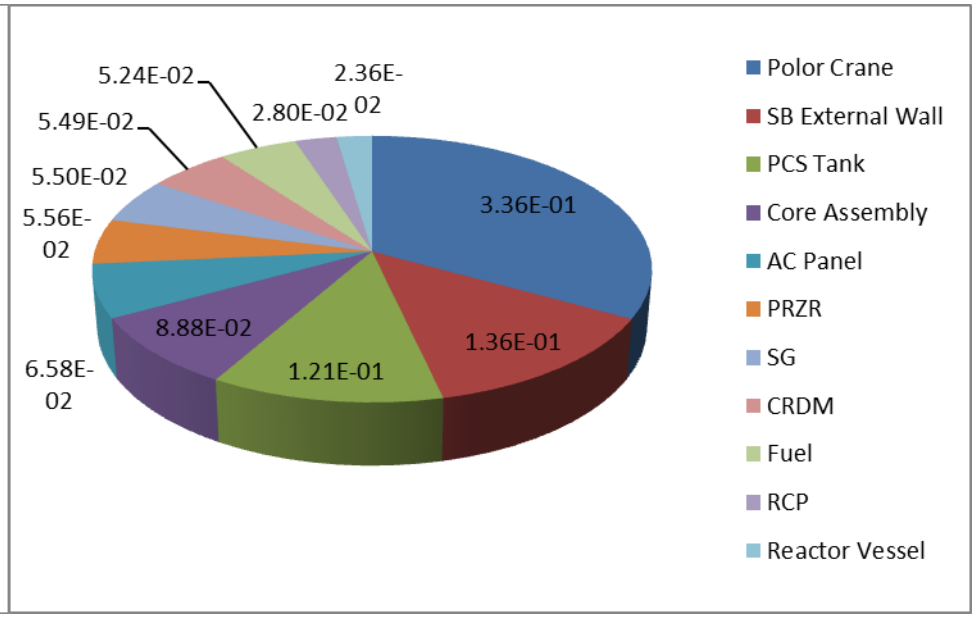
• seismic PSA (2013-2017)

Preliminary Seismic CDF = 2.00E-08/y (mean)



FV Importance



On-Going R&D Activities

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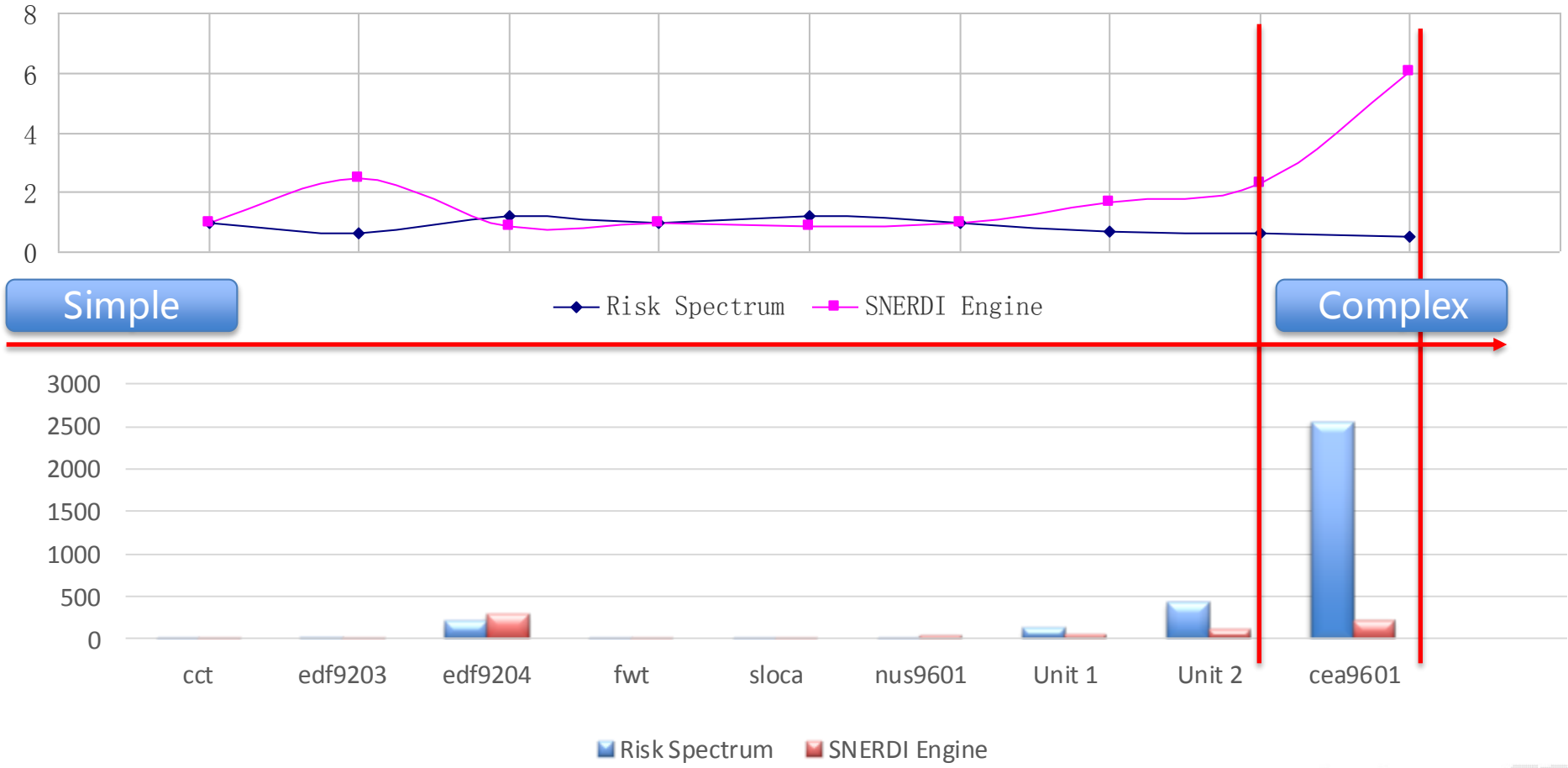
ET/FT Analysis Engine

- **Algorithm**
  - **BDD：** Binary Decision Diagram
  - **ZBDD：** Zero-suppressed Binary Decision Diagram
- **Accuracy**
  - Relative Error: ±2%
- **Speed**
  - Less than 2 mins for regular plant level model on PC
- **Capability**
  - Plant level PSA model solving with high efficiency
  - Compatible with RiskSpectrum and CAFTA
  - Can be Integrated into Risk Monitor software as a third party Engine

On-Going R&D Activities

国家核电 SNPTC 上海核工程研究设计院 SHANGHAI NUCLEAR ENGINEERING RESEARCH & DESIGN INSTITUTE

ET/FT Analysis Engine



Performance comparison with RiskSpectrum (same environment)

Risk Monitor Development

- **Structure**
  - AMP (Apache, MySQL, PHP), Browser /Server
- **Performance**
  - Integrated with BDD-based ET/FT Analysis Engine for a faster speed
  - Capable of providing risk figure, importance indication, schedule risk curve, DID status, etc., necessary information for risk monitor and management
  - High server load capacity and stability
- **Safety**
  - Strict user privilege management
  - Malicious network attack defendable
  - Data backup
- **User Experience**
  - Friendly and simple interface
  - Interactive charts with supportive information

On-Going R&D Activities

国家核电 SNPTC 上海核工程研究设计院 SHANGHAI NUCLEAR ENGINEERING RESEARCH & DESIGN INSTITUTE

Risk Monitor Development

核电厂风险监测器
NUCLEAR POWER PLANT RISK MONITOR

电厂当前状态 | 制定维修计划 | 设置 | 帮助 | 高巍 | 用户管理 | 从本系统注销

一号机组 功率运行 正常

电厂配置和计算

查看详细信息

电厂当前风险状态

CDF(/年):5.64E-6
LRF(/年):9.91E-8
AOT:2.8 月

目前后撤设备

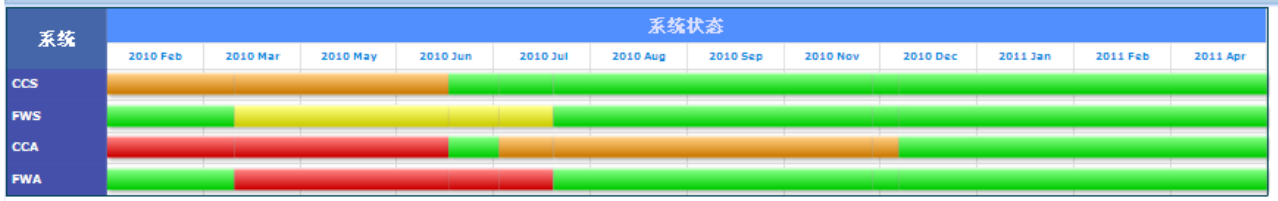
名称	类型	后撤时间	原因
ACATK001	部件	2011-06-07 16:48:37	计划性维
FWAHV057	部件	2011-06-07 16:48:37	计划性维
CCAPM01A	部件	2011-06-07 16:48:37	计划性维

运行建议

状态	要采取的措施	完成时间
ACC_A	使硼浓度恢复到限值内。	72小时
ACC_B	使安注箱恢复到可运行的状态。	8小时
	关闭或隔离主给水隔离阀流	

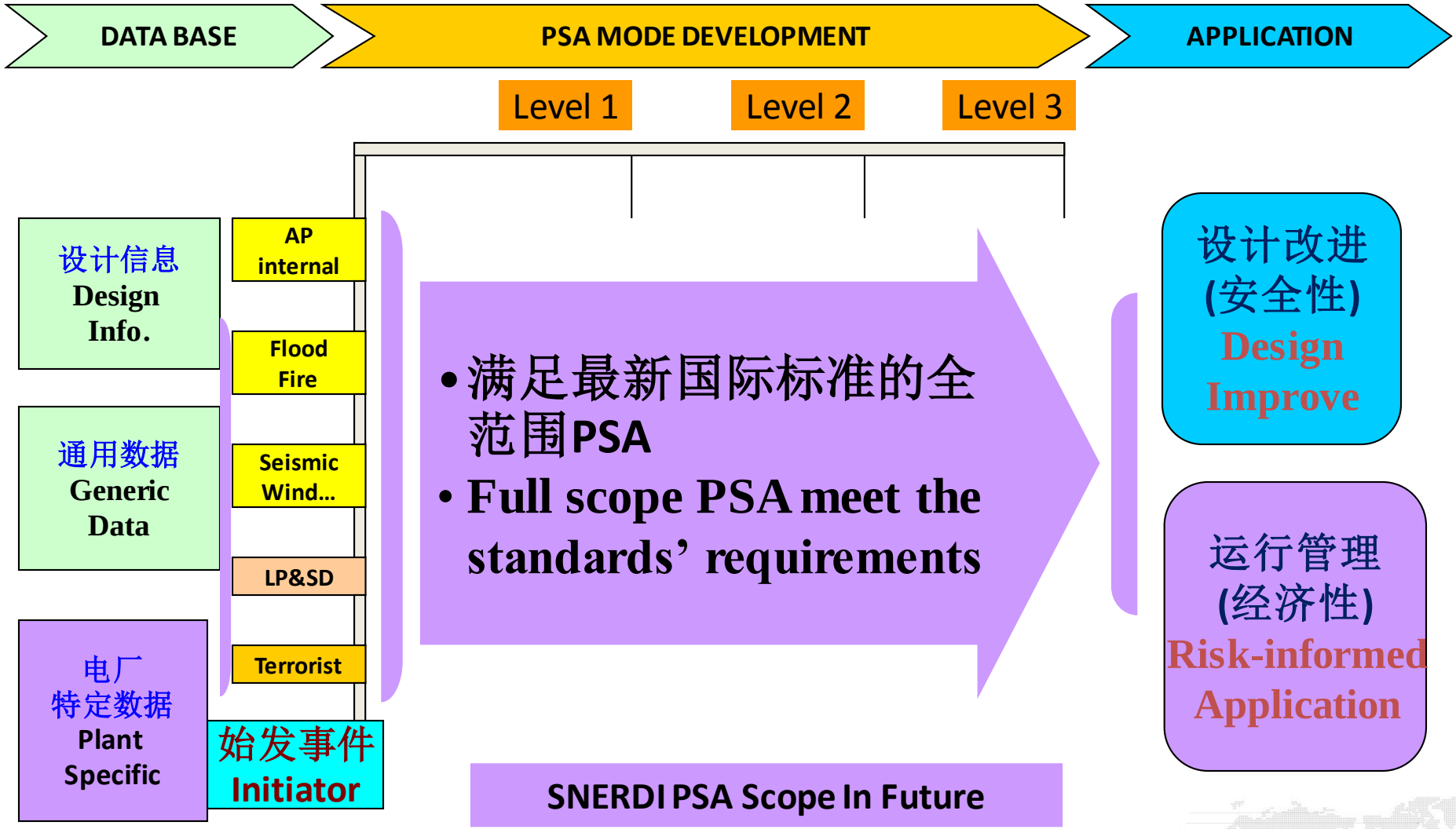
添加后撤设备 | 恢复设备 | 计算 | 保存维修计划 | 生成报表 | 查看/计算重要度

添加/删除



CDF | LRF

SNERDI PSA in future



Any collaboration for above-mentioned areas is necessary and encouraged

国家核电 SNPTC

Thank you for your a

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